Semi-annual EOS Contract Report -- Report #54

Period: January 1- June 30, 1996

Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona

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Report compiled by: K. Thome

Summary: Work by members of the RSG during the past six months consisted of Science Team support activities including the attendance at meetings related to MODIS, writing of the Validation Plan for ASTER and MODIS calibration, and work on the atmospheric correction of ASTER data and the solar-radiation-based calibration (SRBC) of MODIS. First measurements were made with the SWIR CCR. We continued improvements to our calibration facilities and blacklab including upgrades to software to simplify data collection. We received a new Cimel TIR field radiometer and began characterizing it. Machining of the cosine collector for the diffuse-to-global meter was completed. A comparison of three radiometer calibration techniques was completed and work began on processing AVIRIS data for last July's Lake Tahoe campaign. Field work activities were continued with a May-June campaign to Lunar Lake in Nevada coordinated by P. Slater. This trip was a joint campaign with representatives of the Japanese ASTER science team, US ASTER science team, MISR, and South Dakota State. The goal of the campaign was to collect data to allow comparisons of predicted, at-sensor radiances.

Dr Edward F. Zalewski joined the RSG on June 3 as a Research Professor. Briefly, his past experience includes 20 years at NIST where he earned an international reputation for his pioneering work on the development of detector-based calibration. He joined Hughes Danbury Optical Systems in 1990 where he has been in charge of designing and testing the calibration systems for NRL's HYDICE and DOE's Multispectral Thermal Imager. With Slater's reduction to about half time in June, Zalewski will assume responsibility for the supervision of the RSG.

Introduction: This report contains eleven sections. The first nine sections present different aspects of work performed under our contract. If appropriate, each section covers five areas; task objective, work accomplished, data/analysis/interpretations, anticipated future actions, and problems/corrective actions. The first nine sections are: 1) Science team support activities; 2) Cross-calibration radiometers; 3) Mobile laboratory; 4) Bi-directional reflectance distribution function (BRDF) meter; 5) Diffuse-to-global meter; 6) TIR field radiometers; 7) Calibration laboratory; 8) Algorithm and code development; and 9) Field experiments and equipment. The tenth section contains information related to faculty, staff, and students, and the eleventh section summarizes papers published and submitted.

Science Team Support Activities: This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the past six months this included the attendance at team and other related meetings and completing assigned action items.

ASTER Activities: "Validation Plan for the on-board calibrators and the vicarious calibration of ASTER and MODIS", authored by P. Slater, S. Biggar, P. Spyak, K. Thome, P. Abel, H. Kieffer, and F. Palluconi was submitted to the ASTER and MODIS offices at JPL and GSFC on March 7. Biggar, Slater and Thome met with A. Kahle and Palluconi of JPL and K. Arai and S. Machida of the Japanese ASTER Science Team on March 11 at the RSG to discuss the ASTER Calibration and Validation Plans. Thome sent comments to M. Pniel and G. Geller of JPL regarding the size of the look-up table for the VNIR/SWIR atmospheric correction for ASTER and emailed comments on atmospheric correction CPU requirements to Pniel. Thome also sent input to C. Leff for the ASTER software description document and sent A. Schwartz comments on the ASTER Software Data Requirements document. Thome attended an ASTER QA/Testing Workshop in Seattle and sent a revised validation plan for the ASTER atmospheric correction to S. Hook of JPL.

Slater and Thome attended the Validation Workshop at GSFC from May 8-10 and the EOS IWG in Greenbelt from May 13-15. Thome also attended the AM-1 Land Workshop in College Park from May 16-17 where he presented the current status of the ASTER atmospheric correction algorithm. The two attended the ASTER Science Team meeting in Pasadena from June 10-14 where they summarized, together with other participating Team members, the vicarious-calibration-comparison campaign that took place in Nevada earlier in the month. Thome made several presentations to the Atmospheric Correction Working Group including the results of a study looking at the resolution of the look-up table for the atmospheric correction. Biggar and E. Zalewski attended the calibration sessions of the meeting on June 13 and 14.

MODIS Activities: Slater attended an MCST review at GSFC in January where he presented a progress report on RSG activities since the last review. He supplied W. Esaias, the chair, several comments on the MCST presentations which were incorporated into the final report. Slater forwarded a set of view graphs to J. Butler describing plans for a joint vicarious field campaign from May 30 to June 7. Butler used these for a presentation at the Land Test Site meeting at GSFC March 18 and 19. Slater attended this meeting and chaired two splinter sessions on vicarious calibration which resulted in a report written by Butler. On the second day, Slater was also involved in a discussion of how the ASTER and MODIS Validation Plans should be presented. The meeting included Butler, B. Guenther, Kahle, M. King, R. Murphy, S. Reber, P. Sellers, and D. Starr. It was decided the ASTER and MODIS Plans should be submitted separately. A decision was not reached on the division between the MCST Validation Plan and the one referred to above. Murphy was to lead a discussion on this matter April 30 at the Calibration Working Group meeting preceding the MODIS Science Team meeting. On March 20 Slater attended an MCST meeting at which Murphy, M. Roberto and R. Weber were also present. Validation Plan strategy, reflectance- and radiance-based calibration were discussed.

Slater and Biggar discussed by telecon the SRBC of MODIS with T. Pagano of SBRS. Subsequently an email was sent to several people at SBRS and GSFC regarding the suggested approach agreed by telecon. Basically, it involves writing a Test Agreement, to outline the approaches, implementation, error budgets and costs of the UA method and the GSFC method. This was sent to R. Weber. Biggar and J. Young of SBRS determined the heliostat mirror may not be flat enough for the experiment. Subsequently, at the Quarterly Management Review at SBRS the week of March 25, it was concluded that both the radiance and reflectance SRBC experiments should be performed for MODIS. Biggar accompanied Waluschka to test the optics of the heliostat mirror. Biggar collected and evaluated spectrometer data of the mirror.

P. Spyak reviewed 'Radiometric Calibration Effects of NFR (size of source): CPR action item #20" memo by J. Young of SBRS and provided comments to E. Knight. He also reviewed Knight's SPIE paper entitled "Effect of polarization on the application of radiometric coefficients to infrared earth scenes." Biggar and Slater attended the MODIS Calibration Group meeting on April 30 and the MODIS Science Team Meeting May 1-3 in Washington, D. C.

Other EOS Related Activities: Slater was awarded the William T. Pecora Award in Las Vegas on February 27 for his contribution to remote sensing in the area of radiometric calibration. Biggar, Reeker, Spyak, and Thome attended the award presentation. Slater met with G. Asrar on January *24* and discussed the progress of three RSG students who have Earth System Science Fellowships. He discussed SeaWiFS related matters with R. Frouin and sent him material needed for the Moscow meeting Frouin attended one-week later. On March 16 and 17 Slater attended the SWAMP meeting at Valley Forge.

Biggar and Slater attended a HYDICE meeting and presented results of in-flight stability checks and cross-comparisons between HDOS, UA, MTL, and JPL calibrations. These topics will be presented at the SPIE Denver '96 meeting by Slater and Biggar. Biggar also submitted two abstracts to the Denver meeting on HYDICE out-of-band problems and HYDICE laboratory radiometric calibration.

R. Parada attended the IVOS meeting in Toulouse on Feb. 19-20 and gave a brief talk on current work being done by RSG. Crowther presented his work on modeling integrating spheres at the 1996 Council on Optical Radiation Measurements (CORM 96) meeting in Gaithersburg the third week of May. C. Gustafson presented a talk at IGARSS '96 in Lincoln, Nebraska on the cross-calibration of Landsat and SPOT using White Sands. Thome met with X. Briotet of CNES on April 2 to discuss radiative transfer codes used for vicarious calibration. Thome was named to the Landsat-7 Science Team for his proposal titled "Absolute radiometric calibration and atmospheric correction of Landsat-7 Thematic Mapper. " He was also asked to participate on the

Science Advisory Team for the New Millennium Project's, Earth Observer-1 and attended a meeting related to this June 24 and 25 at GSFC.

Cross-Calibration Radiometers: This section describes work to design, fabricate, test, and calibrate a set of preflight cross-calibration radiometers (CCRs). These radiometers are to cover the wavelength region from 400 to 2500 nm. To accomplish this, two radiometers have been constructed, each optimized for a specific portion of the spectrum. They will have very low stray light and polarization responses, exhibit sharp, well-defined fields of view and spectral response profiles, and be ultrastable with respect to temperature and time. The radiometers will be used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors.

VNIR CCR: The objective of this project is to design and build a 400- to 900-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance using pressed PTFE (Algoflon) targets. Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters and two precision apertures determine the throughput. Heating the detector assembly, filters, apertures, and amplifier to a stabilized temperature, a few degrees above ambient, provides thermal control of the system. The system uses a high accuracy voltmeter connected via GPIB to digitize the amplifier output. A commercial datalogger digitizes ancillary information such as detector temperature, and controls the amplifier gain through digital output ports. This datalogger sends the serial digital data to an MS-DOS compatible computer.

Biggar and E. Nelson successfully tested the new VNIR CCR but are debugging controller/computer problems. Biggar used the prototype to measure our FEL lamps for comparisons of Langley and lamp-based calibrations of B. Schmid's solar radiometer. Biggar also used the radiometer to measure the radiance from a barium sulfate panel with the same FEL lamp and radiometer and began data reduction. Nelson modified the shipping rack of the CCR to accommodate the lock-in amplifier for the SWIR CCR and mounted the Hydra and SC5000 SIS controller. He is completing thermal and baffle modifications for the second version of the VNIR

CCR. Biggar and J. LaMarr made SRBC measurements using the prototype, and Biggar, Nelson, and C. Burkhart developed a new sight for the radiometer. Biggar and Nelson modified the thermal control of the radiometer to decrease the warm-up time. It has also been determined there is a thermal oscillation (< 0.5 degree) which is too large.

SWIR CCR: The objective of this project is to design and build a 1000- to 2500-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance and pressed PTFE (Algoflon) targets. The system is designed around an InSb detector. Spectral selection is through interference and absorption filters, and the field of view is defined by a cryogenically-cooled baffle system. A chopper is used to optimize the signal-to-noise ratio.

Work on the SWIR CCR during the last six months included the group receiving bandpass filters from Barr Associates, the dewar/detector from Cincinnati Electronics, shipping cases, and a rotary stage. LaMarr and Spyak learned how to use the lock-in amplifier. LaMarr wrote software to control it and Spyak tested the software with the radiometer. Nelson made a power supply for the detector electronics and various cables. Burkhardt machined a tip-tilt stage for tripod mounting and various other pieces.

Spyak made transmittance measurements including those of the dewar window from 275-3500 nm. He also measured the nine bandpass falters for out-of-band effects from 275-3500 nm and twice measured the in-band transmittance with finer resolution. Spyak measured the dewar/detector responsivity, noise, dark signal, dark noise, stability, repeatability, and field of view. All of the values were near the calculated/design values.

Initial tests of the complete radiometer were made by Spyak. These tests found the instability to be source-limited (<0.11%); the nonrepeatability is source-limited (<O. 11 %); field of view is 3.9 degrees FWHM; the thermal infrared rejection agrees with calculations, the signal-to-noise ratio is >10,000 for the signal levels being used. Spyak also used the radiometer to examine our 40-inch spherical-integrating-source's uniformity, drift, and interactions with radiometers that are being used with it.

These initial tests indicated that minor mechanical modifications were needed and Burkhardt made these modifications. The field-of-view measurements found it to be asymmetric and did not fall off as quickly as desired on one side. The cause was determined to be multiple reflections between the dewar window and the bandpass filters. This was corrected by having Cincinnati Electronics fabricate a new dewar cap to tilt the dewar window by 10 degrees rather than 2 degrees. Following these modifications, Spyak measured the radiometer's stability, repeatability, band-to-band consistency, signal to noise, and field of view. He also repeated the sphere uniformity, sphere drift, radiometer interaction measurements. These data are currently being analyzed but it appears the field-of-view problem has been fixed.

Mobile Laboratory: The objective of this task is to provide a mobile laboratory for 1) storage and transportation of equipment; 2) electricity (AC and DC) for equipment; and 3) shelter from the sun, heat, and cold for computers and people during measurements and for all of our equipment overnight at experiment sites.

The mobile laboratory was used during both the March trip to Ivanpah and the May-June trip to Lunar Lake (both of which are described in more detail below). There was no real chance to test the trailer in an operational sense during the March trip because of poor weather. The May-June campaign provided an excellent test of the trailer because of the test site's remote location. There were no difficulties getting the trailer to the site and it was at the site from May 30 until June 4. The trailer operated as designed, supplying electric power for the RSG for the duration of the trip (six days total), as well as for several other groups which participated in the campaign. The trailer also provided an unplanned bonus as it was used as shelter for people to sleep at the site. This prevented the need for people to leave the hotel in Ely at 3:00 am to arrive at the site in time to collect the needed early morning data.

BRDF Meter: The objective for this task is to design and construct a device, and develop software for measuring the directional reflectance and inferring the bi-directional reflectance distribution function of the ground. The basic design incorporates a fisheye lens and a CCD-array detector.

Spyak and Thome used a collimator to look at the stray light characteristics of the camera. The signal in pixels adjacent to that illuminated by the collimator are 2.5% to 17% of the near saturated value in the center. These percentages fall to less than 1 % within another pixel and are down to noise levels within four pixels from the center pixel. Further measurements with more severe off-axis illumination are planned.

Thome also collected data to map the CCD-array to view angle, determined a method to repeatably point the system vertically and determine the camera's height above the ground, and used the software provided with the camera to collect data in an automated fashion.

Work to be done in the next six-month period includes completing the mapping of the camera to view angle, determining a simplified data collection routine, and developing software to calculate ratios of vertically collected data to off-axis data.

Diffuse-to-global meter: The objective of this task is to design and build an instrument to collect diffuse-to-global irradiance data. By comparing the diffuse downwelling irradiance to the global (direct plus diffuse), an improvement to the atmospheric correction maybe made which reduces the uncertainty of the reflectance-based method. Currently, global irradiance data are collected using a radiometer viewing a reflectance panel and diffuse data are collected by manually positioning a parasol to shade the panel. The diffuse-to-global meter will collect these data automatically and more repeatable.

B. Crowther completed the mechanical design and drawings of the sphere, sphere housing, and fiber holder for the instrument, and purchased a tripod. Crowther began finalizing details of the designs for the support yoke for the elevation rotation and the column support for the sphere and began revising the leveling base. He investigated the mechanical properties of several aluminum alloys for use in various parts of the diffuse-to-global meter. The 6061 alloy series will be used for most of the structural components, except in high stress areas, where the 2024 alloy series will be used, Both require coatings in corrosive environments, and both possess similar strength characteristics, but C. Burkhart prefers the 2024 series.

Crowther purchased the metal products required by the mechanical design and also purchased the machining tools. Crowther selected Delrin to provide low friction drag on the manual azimuth adjustment because it is harder and holds shape better than Teflon. Crowther designed the mounting system for the sighting telescope used to align the instrument in the field.

He selected a quadrant-cell detector from UDT because of the dimensions of the detector and its availability. The detector was delivered in April. Crowther completed most of the electronic circuit design required to interface the quadrant detector to the motion control system. He began testing the components for the quad-cell detector circuitry and found that standard instrumentation amplifiers will not work.

Two different bearings were obtained for the instrument. One helps support the quadrant-cell detector and the other supports one side of the occultor as it is rotated to different elevation positions. The modifications and components added to the instrument required the centers of mass and mass moments of inertia of both the elevation and azimuth rotations to be computed to properly specify the drive motors. Crowther began the purchasing process of the motion control system, received the system from Aerotech in June, and intends to test the system in July.

Burkhart completed two cosine receptors for the diffuse-to-global meter. Each receptor is in two parts, so Burkhart also looked at Spectralon's ability to hold threads for screws. Burkhart was able to machine the parts according to Crowther's designs, although the fragile nature of the Spectralon material required great care. Crowther plans to characterize the angular response of the integrating spheres in July on Mount Lemon. The machining of one of the cone assemblies for the spheres is also completed. The initial machining of the cone assemblies is being purposely oversized to allow Crowther to test and modify the cone. The oversizing of the cone also compensates for the improper placement by the manufacturer of the fiber optic receptacle. Crowther obtained foam sheeting for maintaining contact between the Spectralon sphere and the top of the aluminum canister which surrounds the sphere. Burkhart also finished machining many of the aluminum housing parts. Crowther sent a number of these parts for anodization. When they have been anodized, they will be powder coated and one piece will be sent to Labsphere for coating.

Crowther purchased some of the supplies that will eventually be used in the angular calibration of the sphere collector for the diffuse-to-global meter. Crowther developed a method for correlating time and wavelength in the Licor LI-1800 after determining the time at which each wavelength is scanned is not a deterministic process, but instead depends on relative radiances of adjacent spectral lines. The time each wavelength is scanned will now be known to better than

0.2 seconds referenced to the DOS clock. This will be the lower limit on the timing accuracy due to the update timing of the DOS clock and the variable digitization timing of the LI-1800. Crowther added a PRT to the LI-1800 to allow a readout of the detector temperature. Unfortunately, the cable built to allow the readout seems to couple a great deal of noise into the system. Crowther is currently looking for a solution to this problem. He also purchased a cooler to better stabilize the internal temperature of the LI-1800. Crowther made revisions to his solar position prediction program so it can now predict solar azimuth, elevation, and zenith angles accurate to 0.010, topocentric Earth-Sun distances accurate to better than 0.01%, and the airmass according to the standard Kasten and Young method.

TIR field radiometer: This part of our work has seen several modifications. The original objective was to construct cross-calibration radiometers to cover the 3000- to 14500-nm spectral region, test these radiometers, and write control and data acquisition software. This plan was dropped because of budget reductions. Instead, it was decided to attempt to construct a field-compatible TIR radiometer which could also operate as a transfer radiometer. This radiometer would be designed for precision only and would cover the 8,000 to 14,500 nm. This project has also been delayed because of budget constraints. We are presently evaluating commercially available systems to determine if they can meet our needs. Specifically, the RSG recently received a TIR radiometer from Cimel and has two Everest TIR radiometers.

M. Sicard returned to the group in December and his work, which will extend until March 1997, will focus on a detailed characterization and calibration of the recently received Cimel TIR radiometer, including both field and laboratory work. Sicard and Spyak decided the primary characterization effort will be noise measurements, field-of-view measurements, linearity tests, absolute calibration, and spectral-bandpass calibration.

Sicard and Spyak measured the field of view of the radiometer to be about 9.5 degrees (10 degrees is the theoretical value). Sicard detected small humps on both sides of the curve which he thought were due to the instrument housing, but painting the housing did not improve the out-of-field response.

Sicard made two linearity tests: one using 8 apertures of different sizes machined by Burkhart, the second using a varying blackbody source over the range of 263 to 353 K. He found the non-linearity of the system to be less than 0.2%. Sicard also measured the instrument's absolute calibration using the blackbody over the same temperature range. Sicard collected noise and noise-equivalent temperature data for ambient temperatures. Sicard also collected data with the system outside in direct sunlight to evaluate how its response changes with increasing ambient temperature.

Sicard used the Cimel TIR radiometer as part of a field experiment the beginning of May in the Jornada Experiment range near White Sands with scientists from INRA and the USDA/ARS, including T. Schmugge of the ASTER team. He will use the data from this experiment to compare measurements from several radiometers. Sicard calibrated our ambient Everest blackbody using our Mikron blackbody and found an emissivity of 0.981.

In other related TIR work, J. Myers was awarded an Undergraduate Research Forum grant to evaluate our Everest IRT and perform various TIR field measurements. Myers began to familiarize himself with the Everest and MMR radiometers and became familiar with the operation of the blackbody simulator. He researched FOV measurements and calibration techniques and determined the Everest IRT could not be accurately calibrated due to limitations with the field of view and because the radiometer housing prevents it from being placed close enough to the blackbody source. This is not a problem for the Everest 4000AL transducer which does not have the housing. Myers became familiar with the Hydra data logger and used it to collect data from the 4000AL while viewing a blackbody set at temperatures from 30 to 75 degrees C at 5 degree C increments.

Calibration Laboratory: The objective of this project is to develop a calibration laboratory that will provide the necessary high-radiometric-accuracy standards and characterization set-ups for 1) the cross-calibration radiometers and 2) the field and aircraft radiometers needed for preflight algorithm and code validation and the actual in-flight calibration of the EOS multispectral imaging sensors beyond 1998, At the start of the reporting period our Optronic monochromator was still broken. The chopper moved when it should not, did not position itself correctly, and did not chop at the set frequency. The system was repaired by the manufacturer. The source power supply then failed and Nelson fixed the problem. LaMarr and Spyak checked its alignment and performed spectral calibrations. LaMarr calibrated the first grating and the shorter wavelengths of the second. The longer wavelengths of the second and the entire third grating were not calibrated because we do not have strong line sources at those wavelengths. Spyak evacuated the InSb dewar for the system. Myers used the Optronic to measure the out of band rejection for several unknown interference filters. The electronic temperature control circuit of the Mikron blackbody failed and was repaired and calibrated by Mikron.

P. Spyak had the blacklab multimeter, power supply and shunt calibrated and renewed our repair, maintenance, and calibration agreements for the multimeter and power supply. LaMarr, Myers, and Spyak began work on blacklab improvements. Myers began investigating possible shutter-chopper assemblies and familiarized himself with the chopper and shutter operations, as well as the lock-in amplifier. Biggar got new versions of the software for the Sun GPIB controller and installed and tested it. He installed and tested a new version of LabView and modified our blacklab software to run on our Sun network. LaMarr set up Windows NT on the blacklab computer and successfully controlled a GPIB instrument through LabView. Spyak and Burkhart made blacklab modifications to mount a field reflectance standard from ASTER Team Member, Arai which Biggar and Spyak calibrated. LaMarr installed Service Pack 4 for Windows NT, wrote directions for alignment of rotation stages in the blacklab, and calibrated our field-reflectance standards for the March and May field campaigns.

Biggar developed software to control the blacklab lamp current to better than a milliamp for over two hours. The software uses the voltmeter to control the output of the universal source which supplies the input to the power supplies. The current is measured via the shunt and a new control voltage is programmed. Biggar found cold air from the air conditioner, blowing on the power supply and voltmeter, causes variations in the “amplifier gain”.

Algorithm and code development: Currently, several algorithms exist to perform our calibration work. The RSG has applied these algorithms as FORTRAN programs which are neither user friendly nor efficiently linked together into a single package. The task objective is to convert these existing codes into ANSI standard C in a user-friendly package with rules-based decision making in the package. The group is now also involved in the atmospheric correction of ASTER data in the solar-reflective portion of the spectrum

Scott continued development of the cross-calibration software being written in IDL. Currently, most of the development centers around the creation of user interfaces using IDL widgets (graphical user interfaces). Specifically, a general module architecture is being developed comprised of functions and capabilities to be shared by all modules. Such items as the implementation of the Event_Handlers, the program exit function, the method in which variables will be passed between modules, are all being developed to ensure commonality between modules. Scott received a new IDL Widget Development manual from Research Systems that has assisted greatly in this part of the program development effort. She is nearly finished with the file manager module but has resorted to using multiple event handlers so users can change inputs without crashing the program. Scott has also finalized the transfer of data from one module to another, and from one program to another.

Gustafson developed cross-calibration software which processes all three SPOT-TM band pairs and began to use the October 1994 data set to simulate larger footprint sensors. From these data sets she created error images of the difference between radiances determined from calibration coefficients derived from the reflectance-based approach at Chuck Site to those derived from cross-calibrating the selected pixel to SPOT-HRV. Gustafson created l-km spatial resolution TM images using the White Sands data set. She created similar error images described above for the case of cross-calibrating the low-spatial resolution TM data to SPOT-HRV. This was done using the image registration from the high-spatial resolution images and then also for the case where the images were “misregistered” by 0.5 km. In both cases, several portions of the White Sands area provided cross-calibration coefficient within 3% of the reflectance-based approach. One problem is that these areas can be in different locations for different bands. This points to the importance of proper spectral characterization of any test site used for cross-calibration. Gustafson intends to focus on the errors in misregistration by using the 30-m TM image to calibrate the l-km, simulated image. This will remove any uncertainties due to spectral differences.

Thome continued work on the ASTER LUT generation and tested the doubling/adding RTC from T. Takashima of ASTER to prepare comparisons with Gauss-Seidel results. Thome also began evaluating errors in predicting TOA radiances from interpolation of LUT results. This work will be used to attempt to reduce the size of the ASTER LUT.

Parada organized the multiple versions of the Successive Orders RTC for use in upcoming sensitivity and calibration work. He finished a sensitivity study of Successive Orders using permutations of the input parameters based on nominal conditions for Lake Tahoe and the "open, clear ocean. " He modified the code to include an updated wave-slope model and began trials to compare the results to the old model. While doing this he determined Successive Orders does not work for low windspeeds (below about 2 m/see) because the probability density function is too sharply peaked for the algorithm to adequately partition and integrate. As suspected, substantial discrepancies (as great as 100%) occur in the region of sunglint. In addition, sizeable errors (over 2%) occur for the VNIR far from sunglint. Parada developed a low-windspeed "patch" but this was not successful. Thus different options must be selected depending on the windspeed. A synopsis of the findings will be sent to the code creator/manager J. Deuze. Parada and Santer discussed ways to use Successive Orders with aircraft measurements to retrieve TOA radiance measurements. Parada finished an evaluation of methods for transferring radiances up through remaining atmosphere to TOA, and he compared results from exact and approximate modeling of gaseous absorption over low-reflectance targets using code provided by P. Dubuisson of the University of Littoral.

Work during the next six month period will focus on developing an IDL-based version of the aerosol inversion software and directly linking this software to the output of the spectral optical depth data. The water vapor retrieval software will also be linked to this software to allow columnar ozone and water vapor to be determined. These results will then be linked directly to the radiative transfer calculations. Parada will adapt the software he developed in France to the RSG's computers. He will also complete the sensitivity analysis of the radiance-based approach over Lake Tahoe.

Field Experiments and Equipment: The objectives of the field experiments are to test new equipment, determine needed improvements, test retrieval algorithms and code, and monitor existing satellites in much the same way as we shall for EOS sensors.

R. Parada started a report detailing three methods for calibrating our field radiometers. He processed MMR measurements from the October, Rayleigh-based calibration data sets and compared the results with the lamp-based and SRBC approaches. Poor agreement was found in some cases since the spectral transmittances of the band filters have not been measured. Parada carried out an error/uncertainty analysis of the Rayleigh-based calibration method, refined the error bars used for the code inputs, and began computing gaseous transmittances for this work. He formulated a spreadsheet to compute the lamp-based MMR calibrations using new lamp irradiance measurements from Schmid and Biggar.

JPL supplied Parada with an AVIRIS image of Lake Tahoe collected during last summer's Lake Tahoe experiment. He stripped off the MMR bands from the image but is still waiting for header file information from JPL to use in registering the image data to the research vessel during overpass. He investigated the possibility of retrieving the aerosol imaginary index of refraction from aircraft-based measurements over Lake Tahoe but the results are not promising.

M. Chami, a visiting French student who joined the group during January, looked at the Lake Tahoe data collected last June. He processed the atmospheric measurements to obtain the needed input parameters for the Successive Orders radiative transfer code and modified a new version of this code to include the radiative transfer in water. Simulations with Successive Orders were performed with the optical parameters derived from the ground measurements to perform an atmospheric correction of the aircraft data. He wrote software to read the AVIRIS images and atmospherically corrected both the MMR and AVIRIS data. The lake-level reflectance of the MMR is consistent with AVIRIS and seems to validate our model atmosphere. Directional effects of the surface are observed in regions of high scattering on the lake. Chami also started to use the hydrolight code for in-water radiance calculations to study these high-scatter areas. He made several attempts, with the help of simulations by hydrolight, to understand the measurements from last June over Lake Tahoe. He continued to develop software to use in-water measurements in the successive orders radiative transfer code.

The ASD FieldSpec was modified to have a longer fiber optic and the manufacturer also upgraded the SWIR spectrometers. Gustafson collected data of the VNIR CCR's six-inch SIS to evaluate the spectroradiometer. The upgrade of the system appears to have reduced the noise in both SWIR spectrometers. The upgrades now require the system to be warmed up for at least 30 minutes to ensure the system is thermally stable. In addition, the VNIR data at wavelengths longer than 850 nm is affected by heat from the SWIR TE coolers. Gustafson downloaded the alpha version of a new ASD FR executable program and will test it for ASD. Just prior to the Lunar Lake campaign, the system malfunctioned and Gustafson arranged for it to be repaired. It was shipped to Ely where it arrived in time for use on the trip. After its use at Lunar Lake, it was decided to investigate additional external power. Gustafson investigated this but found the options to be quite expensive. P. Nandy developed IDL code to directly read the binary data filed from the FieldSpec. This will eventually allow us to skip converting the data to ASCII format and thus reduce the amount of disk space required. We intend to use the FieldSpec for the planned trip to Lake Tahoe in July. Gustafson will check the system's use over water to determine the best way to collect the data at Lake Tahoe.

LaMarr read the manuals for the A/D converter and the digital IO boards of the autotracking solar radiometer and continued evaluating the filters for the system. He purchased a new stepper motor and control unit to test a new encoding technique for the filter wheels, and began preparing to install and test the digital 1/0 and A/D conversion boards.

Members of the group performed numerous action items in preparation for the field campaigns to Nevada. Crowther painted labels on our Exotech boxes. Spyak received information from Labsphere on large Spectralon panels for field use and used this to obtain an 18-inch square, monolithic panel from Labsphere. Gustafson obtained a new case for the MMR. Myers learned to setup the met station and became familiar with the test sites used by the group. LaMarr obtained cases for our Tracer Radiometric Calibration Targets. R. Kingston began working with our Polycorder XL data loggers. Spyak and Thome took part in a scouting overflight of Lunar Lake and Railroad Valley organized by M, Helmlinger of the MISR group at JPL. M. Moriyama of ASTER and B. Gaitley of MISR also made the trip. The group shot video and still-photography of both sites. Sicard determined a method for mounting the Cimel TIR radiometer to a yoke. Burkhart and Sicard constructed the yoke mount and tested it. Spyak defined the methods to be used to analyze the TIR data from the Lunar Lake and Railroad Valley field trip.

From March 12-16, Biggar, Myers, Slater and Thome visited Ivanpah Playa, Lunar Lake and Railroad Playa to familiarize the Japanese with the sites and collect sample data. Poor weather prevented the collection of usable data, but the trip helped significantly with the planning of the vicarious calibration comparison campaign held from May 30-June 4.

Eight members of the group made the trip to Lunar Lake. The group left Tucson on May 28 and arrived in Ely on May 29. May 30 was used to setup the mobile laboratory at the Lunar Lake site and to determine the target used for the vicarious calibration comparisons. For the most part, the weather was good and sufficient data sets were collected by June 4. Three other groups participated in the portion of the campaign devoted to comparing predicted radiances at the top of the atmosphere. Slater, Spyak, and Thome used June 5 to further examine Railroad Valley including the collection of surface reflectance spectra over a 2-km long section of the playa. The group arrived back in Tucson on June 6.

File Contains Data for PostScript Printers Only

Figure 1 Comparison between Lunar Lake surface reflectances derived from the ASD FieldSpec FR and the Barnes MMR.

Gustafson, P. Nandy and Thome processed the ASD data from the Lunar Lake campaign. The trip to Lunar Lake offered an excellent opportunity to collect field data with the ASD to compare it to data from our Barnes MMR. Figure 1 shows an example of the average reflectance retrieved from averages of 80 data points collected of the playa along a 240-m path. These data were collected relatively close in time so solar and atmospheric effects are at a minimum. The standard deviation of the averages for both instruments was around 1 % for wavelengths not affected by atmospheric absorption. As can be seen from the figure, the agreement between the two systems is quite good, The differences range from less than 0.002 in reflectance for MMR band 5 to 0.056 for band 7. Of course, the agreement for band 7 is expected to be better when the ASD data are band-averaged to produce the MMR-bands. The absorption feature in the SWIR present in the playa data is a good example of how critical it will be for our group to use the hyperspectral data to accurately characterize the radiance at the sensor for the reflectance-based calibration approach.

Myers and Sicard began reducing the TIR data from Lunar Lake. The two, along with Spyak, evaluated the preliminary results and have begun to investigate approaches to further reduce the data.

Future work in field experiments will include a trip to White Sands in October for a Landsat-5 TM calibration. This trip will be used to collect a test data set for the BRF camera, further evaluate the ASD FieldSpec FR, and test the autotracking solar radiometer. The group will also travel to Lake Tahoe at the end of July. Parada began making plans for this trip which will focus on evaluating the radiative transfer codes used to predict at-sensor radiance. We also will collect TIR data of the lake to evaluate possible techniques for predicting at-sensor radiances in the TIR and attempt a data collection for the calibration of NOAA-14 AVHRR.

Faculty, staff, and students: The personnel presently associated with the RSG are as follows. Faculty: Biggar, Slater, Spyak, Thome, and Zalewski. Staff Burkhart, Kingston, Nelson, and Reeker. Students: Crowther* (Ph.D.), Gustafson (Ph.D.), LaMarr (Ph.D.), Myers (undergraduate), Nandy (Ph.D.), Parada* (Ph.D.), Scott* (Ph.D.), and Walker* (Ph.D.). Those with an asterisk following their names have passed the Ph.D. Preliminary Examination and are mainly working on their Ph.D. research. Crowther has a NASA Fellowship under the Graduate Student Researchers Program, and Parada has a NASA Global Change Fellowship. Walker is self-supported, leaving three graduate students supported by this and other contracts. Parada began a six-month stay in France to work with R. Santer on SeaWiFS related topics. Michael Sicard also rejoined the group in December to begin a 16-month stay with us to work on a joint project with Cimel to characterize a recently developed TIR field radiometer.

Publications

Accepted for Publication:

Computer Modeling of Integrating Spheres submitted to *Applied Optics*

B. Crowther

ABSTRACT

A Monte Carlo model for predicting the performance of integrating spheres as a function of incident flux direction is presented. The model was developed specifically to aid in the design of integrating spheres used as cosine collectors but is of general applicability. A method of generating uncorrelated random numbers is discussed. The probability density functions associated with uniform irradiance over a circular entrance port and lambertian reflectors or emitters are presented. A comparison of the model with analytic equations predicting performance for an unbaffled integrating sphere is included. The data generated by the model agree with the analytic solutions for sphere throughput to better than 0.25 %.

Submitted for Publication:

Reflectance properties of pressed Algoflon F6: A replacement reflectance-standard material for Halon submitted to *Applied Optics*

Paul R. Spyak and Carole Lansard

ABSTRACT

The *standard ultraviolet to short-wave-infrared diffuse reflectance material, Halon PTFE - type G-80, is no longer available. As a result, a new diffuse-reflectance standard material must be found. Algoflon F6 is shown here to be an appropriate replacement by presenting measurements of various spectral-reflectance properties of Halon and Algoflon F6. The measurements include: spectral bidirectional reflectance factor (BRF), sample repeatability, and sample lifetime.*

In-flight radiometric calibration of Landsat-5 Thematic Mapper from 1984 to 1994

Submitted to *Remote Sensing of Environment*

Kurtis J. Thome, Stuart F. Biggar, David I. Gellman, Pad R. Spyak, Philip N. Slater, M. Susan Moran*

ABSTRACT

The reflectance-based method is used to determine an absolute, radiometric calibration of Landsat-5 Thematic Mapper for the solar reflective portion of the spectrum for both level-O and level-l data. Results are given for three calibration campaigns at White Sands Missile Range in New Mexico in 1992, 1993, and 1994 and these results are compared to those obtained from data collected between 1984 and 1988. The retrieved calibration coefficients indicate a degradation in the response of Thematic Mapper when compared with the preflight calibration coefficients. The degradation is much larger for the shorter wavelength bands than the longer wavelength bands with differences of 27%, 20%, 15% for bands 1, 2, 3 respectively, between the preflight values and those obtained in 1994. The change in bands 4, 5 and 7 are within the uncertainties of the method.